Computation of the number of neutrino events which can be registered in Borexino detector from the Sun neutrinos flux with energy $E_\nu = 0.862 MeV$

Beshtoev Kh. M. (beshtoev@cv.jinr.ru)

Joint Institute for Nuclear Research, Laboratory of High Energy Physics, Joliot Curie 6, 141980 Dubna, Moscow region, Russia.

Abstract

This paper gives an estimation of the number of neutrinos which can be registered in Borexino detector from the Sun neutrinos generated in reaction $^7Be + e^- \to^7 Li + \nu_e$ with energy $E_{\nu_e} = 0.862 MeV$ in the absence of neutrino oscillations. This number is supposed be between $N^{theor} = 86.45 \div 96.52 \frac{counters}{(day \cdot 100 \quad ton)}$ in dependence on primary neutrino fluxes. Then ratios between number of neutrinos N^{exper} registered in Borexino detector and counted numbers N^{theor}, are $\frac{N^{exper}}{N^{theor}} = 0.49 \div 0.54$. This value is close enough to the same value obtained in $^{71}Ga -^{71} Ge$ experiments in the close energy regions. The value $\frac{N^{exper}}{N^{theor}}$ obtained at supposition that $\theta_{13} \approx 0$ and absence of the resonance effect approximately equal to $\simeq 0.67$ and it is noticeably greater than the above value. Probably it means that the supposition that $\theta_{13} \approx 0$ is not justified and there can be a definite deposit of τ neutrinos.

1 Introduction

In the present time the detector Borexino goes on operating [1, 2]. One of the major tasks of this detector is to measure of the Sun neutrinos flux with energy $E_\nu = 0.862 MeV$, appearing in reaction $^7Be + e^- \to^7 Li + \nu_e$. Measurements of the neutrino flux at this energy are very important since in this energy region the deposit of the resonance mechanism of neutrino oscillations is very small [3, 4]

then if to suppose that the angle mixing $\theta_{13} \approx 0$ only electron neutrino vacuum oscillations can be observed in this case. Usually it is supposed that the deficit of high energy Sun neutrinos caused by the resonance mechanism of neutrino oscillations in the Sun matter.

The value of $sin^2 2\theta_{12}$ obtained in work [5] from the reactor experiment (neutrino vacuum oscillations) is

$$sin^2(2\theta_{12}) \simeq 0.83, \tag{1}$$

then the fraction (part) of electron neutrinos P_{ν_e} is

$$P_{\nu_e} = 1 - \frac{1}{2} sin^2(2\theta_{12}) \simeq 0.615, \tag{2}$$

and the remaining neutrinos are muon ones and a relative portion P_{ν_μ} of these neutrinos is

$$P_{\nu_\mu} = \frac{1}{2} sin^2(2\theta_{12}) \simeq 0.385. \tag{3}$$

If electron neutrinos are registered via the charged current, then $P_{\nu_e}(W)$ must be equal to 0.615. But if neutrinos are registered via the charged and neutral currents (as it takes place in Borexino experiment), then we must add the deposit of neutral current from the electron and muon neutrinos then $P_{\nu_e}(Z^o) \simeq 0.155$ (see the value obtained in SNO [6]) and

$$P_{\nu_e}(W, Z^o) \simeq 0.615 + 0.155 = 0.770. \tag{4}$$

In Borexino detector neutrinos are registered via the neutral and charged currents. If the primary neutrino flux is N_e^o electron neutrinos, then if there are no neutrino oscillations, then this detector can register n neutrinos, which is a sum of events registered via neutral current n^o and charged current $n^{neutral} = 0.155 \cdot n^o$ (value 0.155 is relative portion of generated by neutral current), then

$$n = n^o + n^{neutral} = (1 + 0.155)n^o. \tag{5}$$

If $\theta_{13} \approx 0$ and there are electron neutrino oscillations then via the charged current $n^{charged} = n^o P_{\nu_e}$ neutrinos can be registered and

via the neutral current $n^{neutral} = 0.155 \cdot n^o$ neutrinos (all electron and muon neutrinos interact via neutral current) can be registered and the sum of neutrinos which can be registered in Borexino detector is

$$n^{osc} = n^{charged} + n^{neutral} = (P_{\nu_e} + 0.155)n^o. \tag{6}$$

The ratio between n^{osc} and n is

$$\frac{n^{osc}}{n} = \frac{(P_{\nu_e} + 0.155)}{(1 + 0.155)} = 0.667. \tag{7}$$

This value is the value which can be obtained in Borexino detector if $\theta_{13} \approx 0$ and there are only oscillations of electron neutrinos.

In work [1] it was reported that Borexino detector must detect about 55 $\quad counts/(day \cdot 100 \quad ton)$ neutrino events at the absence of the resonance effect, then the following work [2] reported that this detector must detect $75 \pm 4 counts/(day \cdot 100 \quad ton)$ at the absence of neutrino oscillations.

The purpose of this work is an independent estimation of number of neutrino events which can be registered in Borexino detector from the Sun neutrinos flux with energy $E_\nu = 0.862 MeV$ at the absence of neutrino oscillations.

From the experiments we know that the angle mixing of $\theta_{23} \simeq \pi/4 \quad (45^o)$ [7, 8] and $\theta_{12} \simeq 32^o$ [5]. The author holds the point of view that since the above (other) angle mixings are big, then there is no reason to suppose that the third angle of mixing θ_{13} can be very small (analysis situation with this supposition see in work [9]).

2 Flux of the Sun neutrinos from $^7Be + e^- \to ^7 Li + \nu_e$ reaction computed in framework of the Standard Sun Model

The discussion of the Standard Sun Model (SSM) was given by J. Bahcall in [10]. The flux of the sun neutrinos from reaction $^7Be + e^- \to ^7 Li + \nu_e$ obtained in [10], is

$$N_{\nu_e}^{theor} = 0.47(1 \pm 0.15) \cdot 10^{10} cm^{-2} c^{-1}. \tag{8}$$

Afterward the neutrino flux from this reaction was carried out [3, 11] and values of $N_{\nu_e}^{theor}$ was calculated as

$$N_{\nu_e}^{theor1} = 0.455 \cdot 10^{10} cm^{-2} c^{-1}, \qquad (9)$$

and

$$N_{\nu_e}^{theor2} = 0.508 \cdot 10^{10} cm^{-2} c^{-1}. \qquad (10)$$

In our computations (estimations) we will use the above values for $N_{\nu_e}^{theor}$

3 $\nu_e + e^- \to \nu_e + e^-$ elastic scattering cross section

The elastic scattering of electron neutrino on electron is realized via W (charge current) and Z (neutral current) boson exchanges. In literature they usually take differential cross cross section and elastic cross section obtained in [12] (see also ref. [13]). Then the expression for differential cross section abtains the following form:

$$\frac{d\sigma_{\nu_e e}(W,Z)}{dT} = \frac{2m_e G_F^2}{\pi}[(\frac{1}{2}+\xi)^2 + \xi^2(1-\frac{T}{E_{\nu_e}})^2 - (\frac{1}{2}+\xi)\xi\frac{m_e T}{E_{\nu_e}^2}], \qquad (11)$$

and the expression for the elastic cross section is:

$$\sigma_{\nu_e e}(W,Z) = \frac{G_F^2 s}{\pi}[(\frac{1}{2}+\xi)^2 + \frac{1}{3}\xi^2], \qquad (12)$$

where G_F is Fermi constant, $\xi = sin^2\theta_W$, $t = (k_1 - k_2)^2 = (p_2 - p_1)^2$ (if electron is in rest, then $t = 2m_e^2 + 2m_e E_{e2}$, $s = (k_1 + p_1)^2$ (if electron is in rest, then $s = m_e^2 + 2m_e E_{\nu_e}$), $T = (E_{2e} - m_e)$ - is kinetic energy of the scattered electron.

The expression for cross sections taking into account radioactive corrections, is given in [14]. We will not use these corrections since the uncertainty in calculated flux of the Sun neutrinos considerably exceed these corrections.

The expression for elastic cross section (12) after substitution the value of s has the following form:

$$\sigma_{\nu_e e}(W,Z) = \frac{G_F^2 m_e^2}{\pi}(1 + 2\frac{E_{\nu_e}}{m_e})[(\frac{1}{2}+\xi)^2 + \frac{1}{3}\xi^2] \simeq$$

$$\simeq \frac{G_F^2 m_e^2}{\pi} 2(\frac{E_{\nu_e}}{m_e})[(\frac{1}{2}+\xi)^2+\frac{1}{3}\xi^2] =$$

$$= 1.722 \cdot 10^{-44} E_{\nu_e}(MeV)[(\frac{1}{2}+\xi)^2+\frac{1}{3}\xi^2] \quad cm^2. \tag{13}$$

It is necessary to remark that this expression for the cross section is correct only at high energies when $E_{\nu_e} >> m_e$. At low energies we must take the threshold effect into account, and then E_{ν_e} must be change on

$$E_{\nu_e} \to \frac{E_{\nu_e}}{(1+\frac{m_e}{2E_{\nu_e}})},$$

Then

$$\sigma_{\nu_e e}(W,Z) = 1.722 \cdot 10^{-44} \frac{E_{\nu_e}(MeV)}{(1+\frac{m_e}{2E_{\nu_e}})}[(\frac{1}{2}+\xi)^2+\frac{1}{3}\xi^2] \quad cm^2. \tag{14}$$

The average value for ξ [15] is $0.232 \div 0.234$. However, it is necessary to remark that for the best fitting expression (12) to the experimental data measured in [16, 17] for $\nu_e + e^- \to \nu_e + e^-$ elastic cross section, this value must be $sin^2\theta_W = 0.248$. Therefore in our computations (estimations) we will use this value for ξ. Then the value for expression $[(\frac{1}{2}+\xi)^2+\frac{1}{3}\xi^2]$ is 0.581. At $E_{\nu_e} = 0.862 MeV$ $\sigma_{\nu_e e}(W,Z) = 0.665 \cdot 10^{-44} cm^2$ (now it is not necessary to use radioactive corrections since we have made normalization for the cross section measured in experiments [16, 17]).

In literature there is another expression for $\nu_e + e^- \to \nu_e + e^-$ elastic scattering [18]. These expressions coincide at high energies E_{ν_e}, but they differ at low energies E_{ν_e}. Probably, it is necessary to find out the reason of their discrepancies.

4 Characteristics of liquid scintillator of Borexino Detector

Borexino detector uses trimethylbenzene $C_6H_3(CH_3)_3$ (or C_9H_{12}) and as scintillator $C_{15}H_{11}NO \quad (1.5 \quad g/l)$ [1, 2] is used. The density of trimethylbenzene is $\rho = 0.8761 \quad g \cdot cm^{-3}$ (in our calculations we will

not take into account this small addition related with the scintillator). The molecular weight of trimethylbenzene is $B = 120.19 \quad g \cdot mol^{-1}$. Then number of $C_6H_3(CH_3)_3$ molecules n_M in one cm^3 is

$$n_M = \frac{\rho}{B} N_A = 4.389 \cdot 10^{21}, \tag{15}$$

where N_A is the Avogadro number.

The one molecule of $C_6H_3(CH_3)_3$ includes 66 electrons, then the number of electrons n_e in $1cm^3$ of trimethylbenzene (i. e., electron density) is

$$n_e = 2.897 \cdot 10^{23} \quad cm^{-3}, \tag{16}$$

then 100 ton ($G = 10^5 \quad g$) of trimethylbenzene contains

$$N_e = \frac{n_e G}{\rho} = 3.307 \cdot 10^{31}, \tag{17}$$

electrons.

5 Estimation of the number of neutrinos which can be registered in Borexino detector from the Sun neutrinos with $E_{\nu_e} = 0.862$ MeV

Using the previous computations now we estimate the number of neutrinos N_B (event rates) which can be registered in the Borexino detector in 100 $\quad ton$ of trimethylbenzene during of one day ($t = 8.64 \cdot 10^4 s$).

$$N^{1theor} = N_e \cdot \sigma_{\nu_e e}(W, Z, 0.862 MeV) \cdot t \cdot N^{theor1}_{\nu_e} = 86.45, \tag{18}$$

and

$$N^{2theor} = N_e \cdot \sigma_{\nu_e e}(W, Z, 0.862 MeV) \cdot t \cdot N^{theor2}_{\nu_e} = 96.52. \tag{19}$$

So, the above estimations have shown that the event rates on 100 ton/day in Borexino detector from the Sun neutrinos with $E_{\nu_e} = 0.862$ MeV can be as follows:

$$N^{theor} = 86.45 \div 96.52 \frac{counters}{(day \cdot 100 \quad ton)}. \tag{20}$$

In [2] it was reported that the rate of events registered in this detector is

$$N^{exper} = 47 \pm 7(stat.) \pm 12(syst.) \frac{counters}{(day \cdot 100 \quad ton)}. \tag{21}$$

Thus, the portion of neutrinos N^{exper} registered in this experiment relative to the computations in the framework of SSM are

$$\frac{N^{exper}}{N^{theor}} = 0.49 \div 0.54. \tag{22}$$

This value is close enough to the same value obtained in $^{71}Ga -^{71} Ge$ experiments [19, 20] in the energy regions near to above.

The value for $\frac{N^{exper}}{N^{theor}}$ in expr.(22) is noticeably smaller than the value (0.67) obtained in expr.(7) if to suppose that $\theta_{13} \approx 0$. Probably it means that this supposition is not justified and there can be a definite deposit of τ neutrinos.

6 Conclusion

In this work the number of neutrinos which can be registered in Borexino detector from the Sun neutrinos generated in reaction $^7Be + e^- \rightarrow ^7 Li + \nu_e$ with energy $E_{\nu_e} = 0.862 MeV$ was calculated. This number is between

$$N^{theor} = 86.45 \div 96.52 \frac{counters}{(day \cdot 100 \quad ton)}, \tag{23}$$

in dependence on the primary neutrino fluxes. Then the ratios between neutrinos N^{exper} registered in this experiment and the calculated numbers N^{theor} are as follows

$$\frac{N^{exper}}{N^{theor}} = 0.49 \div 0.54. \tag{24}$$

This value is close enough to the same value obtained in $^{71}Ga{-}^{71}Ge$ experiments [19, 20] in the close energy regions. The value $\frac{N^{exper}}{N^{theor}} \simeq 0.67$ obtained in (7) at supposition that $\theta_{13} \approx 0$ and the resonance effect is absent is noticeably more than the value in (24). Probably, it means that supposition that $\theta_{13} \approx 0$ is not justified and there can be a definite deposit of τ neutrinos.

References

[1] G. Alimonti et al., Astroparticle Physics, v. 16, 2002, p. 205.

[2] C. Arpesella et al., Physics Letters B v. 658, 2008, p. 101; astro-ph/07082251v2, 2007.

[3] J. Bahcall, M.C. Gonczalez-Garcia and C. Pena-garay, JHEP 0408, 2004, 016.

[4] G. L. Fogli et al., Prog. Nucl. Phys. v. 57, 2006, p. 742.

[5] K. Eguchi et al., Phys. Rev. Let. 90 (2003) 021802;

T. Mitsui, 28-th Intern. Cosmic Ray Conf., Japan, 1 (2003) 1221.

[6] Q. R. Ahmad et al., Internet Pub. nucl-ex/0106015, June 2001.

Q. R. Ahmad et al., Phys. Rev. Lett. 89 (2002) 011301-1. Phys. Rev. Lett. 92 (2004) 181301;

[7] A. Habig, Proceedings of Inter. Cosmic Ray Conf., Japan, 1 (20030) 1255;

[8] Ed. Kearns SuperKamiokande Collaboration, Report on Intern. Conf. Neutrino 2004, Paris, 2004.

[9] Kh. M. Beshtoev, JINR Commun. E2-2007-55. Dubna, 2007; hep-ph/0703252v1, 2007.

[10] J. Bahcall, Neutrino Astrophysics, Cambridge University Press, 1989.

[11] C. Pena-Garay, Talk at the conference Neutrino Telescopes 2007, March 2007, Venice, http://neutrino.pd.infn.it/ conference2007/.

[12] G. t'Hooft, Phys. Lett., v. 37B, 1971, p. 195.

[13] L. B. Okun, Leptons and Quarks, M., 1990, p. 151, 209.

[14] J. N. Bahcall et al., Phys. Rev.D v 51, 1995, p. 6146.

[15] Journ. Phys. G (Nucl. and Part. Phys.), v.33 July 2006, p.35.

[16] R. C. Allen et al., Phys. Rev. D, v. 47,1993, p. 11.

[17] L. B. Auerbach et al., hep-ex/0101039v1, 2001.

[18] E. D. Commins, P. H. Bucksbaum, Weak interactions of Leptons and Quarks, Cambrigje University Press, 1983.

[19] Bellotti E., Nucl. Phys.B (Proc. Suppl.), 2001, v.91, p.44

[20] Gavrin V., Nucl. Phys.B (Proc. Suppl.), 2001, v.91,